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Alternative Approaches to Modeling Visual Target Acquisition

by
Charles P. Greening
Rockwell International
for the
Weapons Development Department

SEPTEMBER 1974

Naval Weapons Center
CHINA LAKE, CALIFORNIA 93555

Naval Weapons Center

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

R. G. Freeman, III, RAdm., USN .... Commander

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FOREWORD

This technical report documents the work conducted from June to August 1974 under Naval Weapons Center Contract N00123-74-C-0236. The work is part of a joint services program on air-to-ground target acquisition.

The Joint Technical Coordinating Group for Munitions Effectiveness has established a Target Acquisition Working Group (TAWG) under the Joint Munitions Effectiveness Manual/Air-to-Surface Division. Current TAWG tasks include the description and effectiveness estimation of target markers, research on target acquisition by flarelight, summary and synthesis of existing target acquisition field test data, and the description and evaluation of mathematical models of the visual target acquisition process. This is the tenth report published to date under TAWG sponsorship.

The report was reviewed for technical accuracy by Ronald A. Erickson (TAWG Chairman), Dr. H. H. Bailey (The Rand Corporation), and MAJ Robert Hilgendorf (Wright-Patterson Air Force Base, TAWG Co-Chairman). It was prepared by the Autonetics Division of Rockwell International and is released at the working level for information only.

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(U) This report develops a framework which structures the variety of modeling approaches that might be taken in quantifying visual target acquisition. Significant omissions in current modeling efforts are identified. Past modeling approaches are described, including those emphasizing cognitive and subjective approaches. It is concluded that mathematical modeling is so dependent upon (1) the objectives of the user, (2) the class of situation being modeled, and (3) the methodological orientation of the modeler, that a single model cannot meet all requirements. This report is particularly useful to those engaged in modeling who desire an overview of modeling techniques.

CONTENTS

INTRODUCTION

Autonetics has been under contract to study visual target acquisition modeling and prediction since 1972. Among the tasks performed have been surveys of existing target acquisition models[1,2] and an analysis of elements not represented (or inappropriately represented) in existing models.[3]

One of the results of the work described above has been a growing conviction that the approaches to target acquisition modeling implied by available descriptive materials represented only a portion of the spectrum of feasible approaches to the problem. Specifically, the optical properties of the search and acquisition process have characteristically been treated in considerable detail, while cognitive elements in the process (assuming they are significant) have been treated sketchily, if at all. The evidence for this conviction is discussed in detail in an earlier report.[3]

The relationships between present-day models and their historical antecedents have been discussed and diagrammed in an earlier report.[1] Much of the modeling approach evident in today's models can be traced to the activities of the U.S. Navy Operations Effectiveness Group, under Koopman, during World War II.[4] As will be seen later in this report, the strong Operations Research orientation of the Koopman work has to a considerable extent inhibited the exploration of alternative philosophies in model development.

Other disciplines which might have relevance to target acquisition have also been involved in modeling and prediction since World War II. They include detection theory, decision theory, neuro-psychological investigation, optical image processing, and artificial intelligence,

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1 Naval Weapons Center "Target Acquisition Model Evaluation Final Summary Report" by C. P. Greening. China Lake, Calif., NWC, June 1973 (NWC TP 5536, publication UNCLASSIFIED).

2 - - - - -. *Target Acquisition Model Evaluation: Part 2. A Review of British Target Acquisition Models*, by C. P. Greening, Autonetics Division, Rockwell International. China Lake, Calif., NWC, August 1974. (NWC TP 5536, Part 2.)

3 - - - - -. *Modeling Visual Target Acquisition: Inclusion of Certain Psychological Variables*, by C. P. Greening, Autonetics Division, Rockwell International. China Lake, Calif., NWC, August 1974. (NWC TP 5690.)

4 Chief of Naval Operations, Operations Effectiveness Group. "Search and Screening" by B. O. Koopman. Washington, D. C., OEG, 1946 (OEG Report No. 56, published as CONFIDENTIAL, now UNCLASSIFIED).

among others. While it is not obvious which, if any, of these disciplines might improve target acquisition prediction, they cannot all be rejected out of hand.

The purpose of this report is to erect a framework which will give some structure to the variety of modeling approaches which might be taken, and to identify tentatively the more significant omissions. To this end, a search has been made for sources of modeling approaches which seem to be most relevant. These include, but are not limited to, the cognitive and subjective emphasis suggested in the contract statement of effort.[5]

[5] Contract N00123-74-C-0236, between Naval Regional Procurement Office, Los Angeles, and Autonetics Division, Rockwell International, Anaheim, Calif. 26 July 1973

SOURCES OF ALTERNATIVE APPROACHES

Alternative approaches to modeling target acquisition might arise for a number of quite distinct reasons. They include different classes of search and acquisition events to be modeled, different objectives of the user and different philosophical orientations of the model developer, in addition to the possibly different psychological representations of the acquisition process envisioned in the contract work statement. Each of the above-listed orientations is explored briefly in this section.

CLASSES OF EVENTS

The events to be represented in a target acquisition model vary with both the type of mission and the stage of the mission. An analysis of operator tasks was made during an Autonetics study performed under an Air Force contract. The tasks shown in Table 1 are adapted from that study report.[6]

It is evident from an inspection of the tabulated tasks that different classes of search and acquisition behavior are involved. The detect/recognize/identify sequence upon which several existing models are based appears to be suitable for only limited cases.

Possible alternative modeling approaches, suggested by Table 1 and the related studies, include:

1. A contingent sequence of accept/reject decisions, based upon information received in each glimpse of the terrain. The glimpses could be viewed as inquiries, each having an associated cost in terms of time.
2. A variable level of confidence in the identity of a locale being viewed. Again, each glimpse has an effect on the confidence level, and a cost.

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[6] Air Force Avionics Laboratory. "Multi-Sensor Operator Training - Phase I. Analysis of Operator Tasks and Target Recognition Skills" by O. K. Hansen, J. M. Humes and R. E. Offenstein. Wright-Patterson AFB, Ohio, March 1970 (AFAL-TR-70-4, publication UNCLASSIFIED).

Table 1. Search Behavior Analysis

Search Mode & Phase	Function	Behavior	Necessary Model Characteristics
A. AREA RECON.			
A1. Initiate	Identify area	a. Observe terrain features	Terrain features as "targets" (Indefinite boundaries; complex textures; indirect cues)
		b. Compare with briefing data	Briefing quality & availability
		c. Accept/reject identity of feature	Decision function (Variable criteria; errors & corrections; sequential dependencies.)
A2. Search	Look for objects of military interest	a. Scan area for targets	Scan pattern (Sensitive to search task, flight variables).
		b. Examine "interesting" locations.	"Detection" function (sensitive to expected targets, clutter, clues, off-axis acuity)
A3. Acquire	Establish identity of a target object.	a. Observe features of object.	Recognition function (Sensitive to target size, shape, etc.).
		b. Compare with briefing data	See A1b
		c. Accept/reject identity	See A1c
B. ROUTE RECON.			
B1. Initiate	Identify area	See A1a, b, c	See A1a, b, c
B2. Search	Look on/near route for vehicles	a. Scan along route	Scan pattern (Adapted to Route Recon: follows route; stays ahead of acft; may be off flight axis).
		b. Examine vehicle-related objects.	"Detection" function (Sensitive to vehicles and vehicle related phenomena)
B3. Acquire	Establish identity of a vehicle	See A3a, b, c	See A3a, b, c
C. FIXED/POINT TARGET			
C1. Initiate	Identify IP	See A1a, b, c	See A1a, b, c
C2. Search	Look for target area	a. Estimate range & bearing to designated target location.	Scan pattern (Sensitive to range & bearing error scanned area fixed or ground).
		b. Look for briefed pattern.	"Detection" function (Sensitive to briefing quality, non-target clues).
C3. Acquire	Establish identity of designated point/target	a. Observe terrain features in suspect area.	Recognition function (Sensitive to clue characteristics)
		b. Compare with briefing data.	See A1b
		c. Accept/reject identity.	Decision function (Capable of decision based on non-target clues).

OBJECTIVES OF USER

Those who attempt to represent target acquisition by a mathematical model are undoubtedly moved by a variety of motives. The characteristics of a desirable model may well be different for users with different objectives. A few alternatives are discussed briefly below.

Practical Prediction

The planning of reconnaissance or attack missions involves prediction of target or landmark acquisition, as a function of selectable conditions (e.g., time of day, flight altitude) and uncontrollable factors (e.g., target and background characteristics).

The "ideal model" for practical prediction work might well be one with a minimum of input quantities and a minimum of computation, and with outputs in a form which provide directly usable estimates and which indicate those controllable factors most powerful in their influence on the output.

Not all prediction models necessarily aim at the same sort of prediction. It may be desirable to make a statistical prediction over a class of missions, or the best estimate for a single encounter. Probability as a function of range may or may not be needed.

Scientific Understanding

Among the groups building models of target acquisition are some whose objective appears to be to attain a more thorough understanding of the target acquisition process. While the long-range objective is undoubtedly the prediction of performance, the way to that objective is seen as lying in the area of systematic investigation of the process.

The "ideal model" for increased understanding of the target acquisition process can be quite different from a more immediately practical one, as described above. Here, efficiency and simplicity are not necessary (though perhaps desirable). The necessary characteristics are more likely to be completeness in terms of input functions, explicitness of effects of variables, and outputs with diagnostic power.

One of the classical criteria for the evaluation of theoretical constructs is fruitfulness in suggesting testable hypotheses. Insofar as target acquisition models development can be viewed as a scientific endeavor, this might also be a useful criterion.

Use in Larger Models

Several of the target acquisition models reviewed during previous phases of this study have been parts of a larger model. A striking example is the Stanford Research Institute CRESS/SCREEN series. The overall model involves an engagement, with several hundred objects (vehicles, men, weapons) in specified locations, and a helicopter flying across the engagement area. For such an application, the primary

criteria for a visual search model arise from its interface with the rest of the model. Thus the visual search portion can be viewed as a symbolic "black box" which puts out binary answers to questions such as "did this helicopter pilot detect that tank on a particular leg of his flight." Such outputs as "misidentification" are computed, not because the model builders know what produces that outcome, but because the overall model requires the quantity.

PHILOSOPHICAL ORIENTATION

There is little evidence, in the documentation of the target acquisition models so far reviewed, of an a priori philosophical orientation guiding the model development. Nonetheless, substantial differences do exist, implicitly, in those models. It seems appropriate to examine, as well as can be done by inspection of the finished products, the orientation of the authors, and to see whether still other philosophies exist, leading to significantly different model formulations.

Operations Research Orientation

Most of the models currently in use can be traced, at least in part, to the work of the Navy Operations Effectiveness Group or the Planning Research Corporation, both of which were operations research groups.[7]

The hallmark of an OR approach to modeling is the early selection of a fairly simple mathematical expression, based generally upon one or two sets of data. Subsequent embellishment of the model often proceeds as though the mathematical expression were, somehow, the fundamental "truth" about the phenomenon being modeled.

The implications of this approach to prediction are described at some length in a recent article on forecasting.[8] It is pointed out that the approach is most appropriate in those situations in which the basic laws behind the phenomenon are simple and well understood, as the laws of gravity are. Advantages of the approach, in suitably simple situations, are that it leads to rather simple models, and permits prediction over a wide range of conditions. These "advantages" are illusory, however, in situations in which the assumptions are not met.

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[7] NWC TP 5536 (See Footnote 1)

[8] Mitroff, I. I., and M. Turoff "Technology Forecasting and Assessments - the Whys Behind the Hows" in IEEE Spectrum, Vol 10, No. 3, March 1973

In visual target acquisition, the OR approach appears to have led the modeling work in a particular direction - toward laboratory data on visual performance with simple stimuli. Those are the data on which the model formulations are based, and the models are primarily sensitive to the usual independent variables in such laboratory work - e.g., luminance, contrast and size. Given the initial orientation, this is a highly rational course of action, for nowhere else in the search/acquisition behavior spectrum will performance data be found which are as lawful as, say, the Tiffany data collected by Blackwell and associates.

Empirical Orientation

The empirical outlook is in some ways directly opposed to the OR or analytic approach discussed above. Here the assumption is that "truth" lies in the data. If an analytical expression is used, it is conditional upon its correct representation of the data; hence, new data may force change or abandonment of a formula. In extreme cases, the "model" can become simply a large look-up table.

As is usually the case, the apparently simple "pure empirical" approach becomes more complex upon closer inspection. It may be simple in a case in which causes and effects are simple, evident, and separable (for example, measuring the length of a metal rod as a function of temperature). In more complex situations, however, variables cannot be separated, or even described. Furthermore, assumptions must be made about the behavior of the variable between data points, since a finite set must suffice. Thus there may well be implicit, unrecognized assumptions about analytical form, even in a "pure empirical" look-up table.

Advantages of an empirical approach are the high validity of the model and its sensitivity to new data. Disadvantages are the inability to extrapolate beyond the limits of the input data, the cumbersome nature of the tables/formulations in complex, multi-variate situations, and the lack of insight into the dynamics and interactions characteristic of the system.

In target acquisition modeling, the most nearly empirical approaches are those of Franklin and Whittenberg[9] and the "minimal model" set forth in an earlier report in this series. Both models are based primarily upon field data, rather than the more orderly laboratory detection data. In both cases, the empirical approach was, in some measure,

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[9] Human Sciences Research, Inc. "Research on Visual Target Detection-Part I - Development of an Air-to-Ground Detection/Identification Model" by M.F. Franklin & J.A. Whittenberg. McLean, Va., HSR, June 1965 (HSR-RR-65/4-Dt).

defeated by the richness and variety of the input data. No two field trials ever differ in just one simple variable. Hence, field test results take the form of a complex, interactive, disorderly array of independent and semi-dependent variables, with a certain amount of grouping to provide statistical stability in the performance measures. Such an array is useless in raw form, since there is no way to enter it with a new set of values. Hence, the modeler is forced to impose simplifying "orderliness" on the data, in the form of crudely fitted analytical expressions, or statistical simplifications such as regression equations. These simplifying expressions then take on some of the character of the analytical forms described earlier, with the accompanying shortcomings.

Synthetic Orientations

Mitroff and Turoff, in an article cited above (see footnote 8), distinguish between "Kantian" and "Hegelian" forms of rapprochement between the two simpler philosophies (i.e., analytic and empirical). The two approaches differ primarily in the amount of conflict involved; both agree in the assumption that the "truth" in an investigation lies in a synthesis between the formal statement (analytical) and the data (empirical).

The synthetic approach seems to be best suited to complex, ill-defined problem areas. At best, the early data provide a basis for analytical forms as tentative models; the analytical form points to areas in which new data are needed; the process is essentially endless.

In practice, because of limited resources and shifting goals, the synthetic process has not generally been applied at length in target acquisition modeling. The closest approach appears to have been in the British work, started at the Royal Aircraft Establishment and carried on in the Defense Operations Analysis Establishment and the British Aircraft Corporation.[10] There a ten-year program of theoretical investigation, anchored at frequent intervals to field and simulator data, has been in progress.

Even in the extensive British work, certain supposed advantages of the synthetic approach do not seem to have been achieved. It appears, for example, that there was an early and apparently unshakable commitment to a randomly-searching visual lobe mechanism, because this feature has persisted even when data forced considerable patching and modifying. More significantly, the models have dealt almost exclusively with the optical problem (as have all the models), by-passing the substantial cognitive elements which can be supported by other data.

[10] NWC TP 5536, Part 2 (see Footnote 2).

Pragmatic Approach

The main feature of this approach, as distinct from the synthetic approach, lies in a recognition of the tendency to shape inquiries by goals and objectives. Thus, an investigator, to some extent, finds only what he is looking for unless forced to consider other viewpoints. In essence, a pragmatic approach implies a knowledge of all the other approaches, and a consciousness of their strengths and weaknesses.

The strength of a pragmatic approach lies in its sensitivity to the limitations of all methods of inquiry. It ought to result in superior syntheses because of this consciousness of methodology. The weakness, however, may lie in the tendency to keep expanding the inquiry into an ever-receding succession of methodological discussions.

As was indicated at the beginning of this section, none of the documentation so far reviewed displays the explicit recognition of alternative methods and outlooks that should characterize a pragmatic modeling approach. Whether such an approach would be fruitful cannot be judged.

PSYCHOLOGICAL ORIENTATION

The psychological orientation of the authors of target acquisition models, like their philosophical orientation, must largely be estimated from the products. Possible alternative orientations, not represented in existing models, are largely the result of the author's ruminations over a period of years.

The title of this section — Psychological Orientation — is misleading insofar as it implies that a treatment in terms of theories of psychology is intended. Actually, all that is intended is a brief description of possible alternative ways of viewing the task of the observer in visual search. No attempt will be made to relate these alternatives to psychological theory.

Observer as Optical Detector

Beginning with the OEG air/sea search formulation, most of the acquisition models have viewed the observer as an optical device, characterized by a slewable detector with known sensitivity/angle characteristics. The device is slewed over the search field, either randomly or systematically, until it detects an object. It then fixates the object until it detects a detail which permits a classification decision to be made. In some of the models, the situation is complicated by a "clutter" effect, which accounts for the need to look at and reject some nontarget objects in the search field.

Advantages of this approach to modeling are relative simplicity of input data, the existence of relevant laboratory data for partial validation, and the objectivity of the relevant scene characteristics. Disadvantages include a lack of sensitivity to cognitive factors such

as briefing and training, and an inability to handle many classes of search objects not characterized by simple outlines, fixed dimensions, etc.

Work in progress at the British Aircraft Corporation is demonstrating an extension of the "optical detector" approach to include more complex and subtle target characteristics than heretofore.[11] However, the cognitive elements are still not well represented.

Observer as Decision Maker

Viewing the observer as a decision maker is not intended to imply an absence of visual detection functions in the target acquisition process. Rather, it may provide a different way of structuring the actions. None of the models so far reviewed takes significant account of the decision making process. The SRI model generates values for probabilities of mis-identification and other non-standard outcomes of the search process, but they do not emanate from a decision model.

The decision-making view of visual target acquisition is based in part on experimental work on the target decision process, done at Autonetics a decade ago. It was found that, for fixed, pre-briefed targets, the observer typically acquired the target area well before he was prepared to make an "acquired" response. The subsequent time was spent in examining the target area, comparing with pre-briefed clues, and reducing the feeling of uncertainty about target identity.

At least a part of the decision process is more cognitive than visual. The observer must compare what he sees with a rather abstract set of attributes which he expects the target to exhibit. The expected attributes may have been acquired from a briefing photo (perhaps taken from a different angle, different lighting, etc) or from maps, verbal descriptions, or from analogy with other targets. This process is not simply a visual fitting of two images. Coincidence between a visual feature and an expected target attribute serves to increase confidence in the identity of the target, and vice versa. Non-target attributes (such as relation to an external landmark) are at least as important in this process, for fixed targets, as are direct target attributes (such as color, shape).

In the case of fleeting targets, different attributes become important. It is still true, however, that the "target/non-target" decision depends in part on characteristics other than vehicle shape and size. For example, tracks on one side of a puddle increase the observer's expectation of finding a vehicle on the next segment of road, and will undoubtedly affect his response to other clues.

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11 NWC TP 5536, Part 2 (see Footnote 2).

The construction of a model based upon a decision-chain paradigm would not be an easy task. It is not difficult to set up a flow chart showing a sequence of glimpses, each resulting in a change in level of uncertainty about target identity. But the quantitative relationships between visual perception and target decisions are not known at present. Those portions of the visual model relating to visibility of features would also have to be included, of course.

Observer as Problem Solver

The "problem solver" orientation is meant to imply an active seeking behavior on the part of the observer, instead of the rather passive random or plowed-field patterns of viewing currently assumed. Here it is assumed that the observer has pre-knowledge of target attributes, including terrain indicators, which would be expected to give "early warning" of probable target presence. The observer would then use peripheral vision to direct his glimpses at the likely areas in the terrain. Having fixated a "candidate" area, he would then examine it until he could make a target/non-target decision; then (if non-target) saccade to the next candidate area.

Enough information now exists concerning peripheral vision to permit approximate quantitative prediction of search behavior following this paradigm.[12] A major difficulty for practical use of such a model is the necessity of describing the entire visual field in terms of presumed peripheral indicators.

An alternative approach, using more subjective ratings of "conspicuousness" of targets, is also under investigation in Great Britain.[13]

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12 Greening, C. P. "The Likelihood of Looking at a Target" in AGARD Conference Proceedings No. 100, NATO, June 1972

13 Raynor, A. J. "The Use of Kelly's Repertory Grid Technique for Assessing Subjective Estimates of Important Parameters for Target Acquisition" in AGARD Conference Proceedings No. 100, NATO, June 1972.

CLASSIFICATION OF TARGET ACQUISITION MODEL APPROACHES

DIMENSIONS

The possible alternative approaches described briefly above have come from a number of disparate sources. An attempt will be made here to cast these alternatives in the form of "dimensions," without regard for their orthogonality or congruency. Possible dimensions appear to be:

1. Analytic - - - - - Synthetic - - - - - Data-based

   This dimension represents the spectrum of philosophies described above.

2. Scientific - - - - - - - - - - - - - - - Utilitarian

   This dimension expresses the possible extremes of motivation of the model builder.

3. Optical/Objective - - - - - - - - - - - Cognitive/Subjective

   This dimension expresses the range of views of the function and nature of the observer.

4. Comprehensive - - - - - - - - - - - - - Reductive

   This dimension expresses the possible extremes of approach in terms of the attempt to include as much of the target acquisition process as possible, or to leave out as much as feasible.

5. Target-centered - - - - - - - - - - - Situation-centered

   This dimension expresses the range of search problems from that of looking for a raft on the ocean (no clues except the target itself) to that of looking for a target located in the center of a net of roads, rivers, or other terrain indicia (the target can be identified without even being seen).

CLUSTERING

These five "dimensions" could be viewed as describing 2^5 or 32 distinct classes of models (assuming independence of the five dimensions). However, there is no a priori reason for thinking that each of these classes represents a useful, or even a meaningful model. Nevertheless, it may be instructive to classify existing models to see where they cluster, insofar as this can be done from the available information. The "scientific/utilitarian" dimension will be excluded because it represents primarily an attitude on the part of the model builder, and is not generally discernible from a review of the model. A crude classification of models studied under previous

contract has been attempted, and is displayed in Fig. 1.

Although the classification is crude and subjective, it is apparent that there is a conspicuous lack of models at the "cognitive/subjective" end of the scale. Modelers have, without significant exception, modeled the observer as an optical pattern seeker, rather than as a problem solver. A somewhat less striking tendency is a concentration on target characteristics, as opposed to other scene and situation characteristics. This tendency is probably related to the previous one: <u>if</u> the observer is viewed as a "target-pattern-matcher," the non-target scene characteristics become less important.

MISSING MODELS

The rough outlines of a "missing model" can be deduced from the clustering seen above. Such a model would take account of the entire target environment, and of the observer's cognitive concept or "map" of the target and its surround. The optical properties of the target indicators would not be omitted, but incorporated as necessary.

Some work under way at the British Aircraft Corporation is leading toward the quantification of subjective target and non-target characteristics into acquisition prediction.[14] No known model builder has incorporated this kind of element, together with objective optical properties, into a more general model. Briefing quality, observer training and similar non-target characteristics have also generally been omitted.

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[14] Raynor, A. J. See Footnote 13.

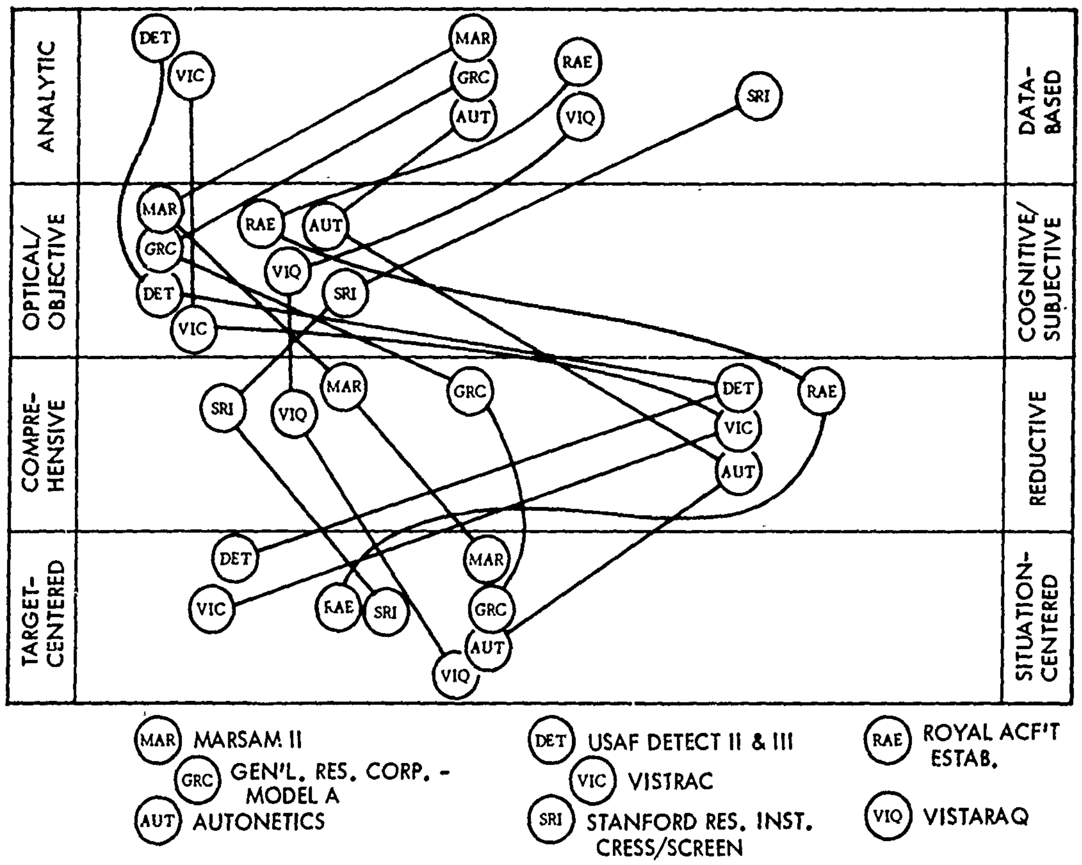

Figure 1. Rough Classification of Models on Four Dimensions

POSSIBLE ALTERNATIVE APPROACHES

The models examined during the past two years have generally shared two somewhat conflicting limitations: on the one hand, they tend to be long and complex; on the other hand, they tend to omit factors known or suspected to be important in some search situations. Two approaches to overcoming these limitations suggest themselves. One is to make an all-inclusive, articulated model, such that intermittently important factors can be included or deleted as needed; the other is to admit that search and acquisition situations differ so much that a collection of distinct models is called for. Each of these approaches will be examined below.

AN ARTICULATED MODEL

A single, articulated model which can expand, contract, and change shape in response to changing requirements makes sense only if there exists some central core of the model which retains its structure throughout. If there were no such central features, the "articulated model" becomes, in actuality, a collection of different models.

The Columbus Format

Perhaps a new model might be expected to take a form similar to an early Rockwell International (then North American Aviation) model, presented by Matthews at the Columbus Division in 1967.[15] The basic idea of that model is to compute a limiting acquisition performance, based on optical properties of the target, and then modify the result by an open-ended series of factors related to speed, masking, target motion, etc. Thus, the equation for probability of acquisition becomes

$$P_{acq} = P_o \cdot F_1 \cdot F_2 \cdot F_3 \cdots$$

where P_o is the optically limited performance, F_n are the modifiers, for factors such as search area, aircraft speed, etc.

The value of P_o is, in turn, also made up of a base value with modifiers:

$$P_o = f(R_s, R_{so}) = f(R_s, R'_{so} \cdot g_1 \cdot g_2 \cdot g_3 \cdots)$$

[15] North American Aviation, Inc. "Extended Program Capabilities for Predicting the Probability of Target Acquisition" by E. P. Mathews, Columbus Division, Report NA66H-606. March 1967.

where R_s is present slant range to target

R_{so} is slant range for a "unit target acquisition" (unit area, zero attenuation, no clutter, etc) probability of 1/e.

R_{so} is slant range for 1/e probability when R'_{so} is modified by "g" factors.

The strength of this paradigm lies in its extreme flexibility. New "F" and "g" factors can be invoked whenever needed, and set to unity when not relevant.

Possible weaknesses in the "core and modifier" model also exist.

First, the assumption of limiting optical performance on a target object as a central, constant term may be open to challenge. For example, in a general area reconnaissance flight, the observer is not looking for any specific, geometric object, but has a much more general set of objectives. He is looking for evidence of military activity. The "modified limiting visual range" concept may not be able to represent that situation adequately.

A second possible weakness in the "Columbus Format" lies in the method of combining the modifiers. As represented above, the "F" and "g" modifiers are assumed to combine in linear multiplicative fashion. The validity of this assumption has not, in general, been established. In fact, significant interactions among modifying conditions are common in field and simulator data. An interactive matrix of modifiers is theoretically possible, but would probably be cumbersome, and would certainly be difficult to validate.

Other Articulated Formats

Another variable format which is, so far as is known, untried, would be one as shown in Fig. 2. Here, the assumption is that all target acquisition processes can be broken down into parallel phases (e.g., search, detection, recognition) and that alternative blocks for each phase could be hooked together to make up overall models.

Such an articulated model would share certain advantages with the type previously described. It can be as flexible as necessary, since blocks can be added or replaced in any category without disturbing the remainder, if the input/output interfaces can be made to match. In addition, the separate functions can be manipulated (or validated) independently, because inputs and outputs can be monitored at each node.

Two potentially serious problems can be anticipated in the construction of an articulated model on this format. First, it is not obvious that all search/acquisition situations of interest can be represented by a parallel block structure. As an example, consider

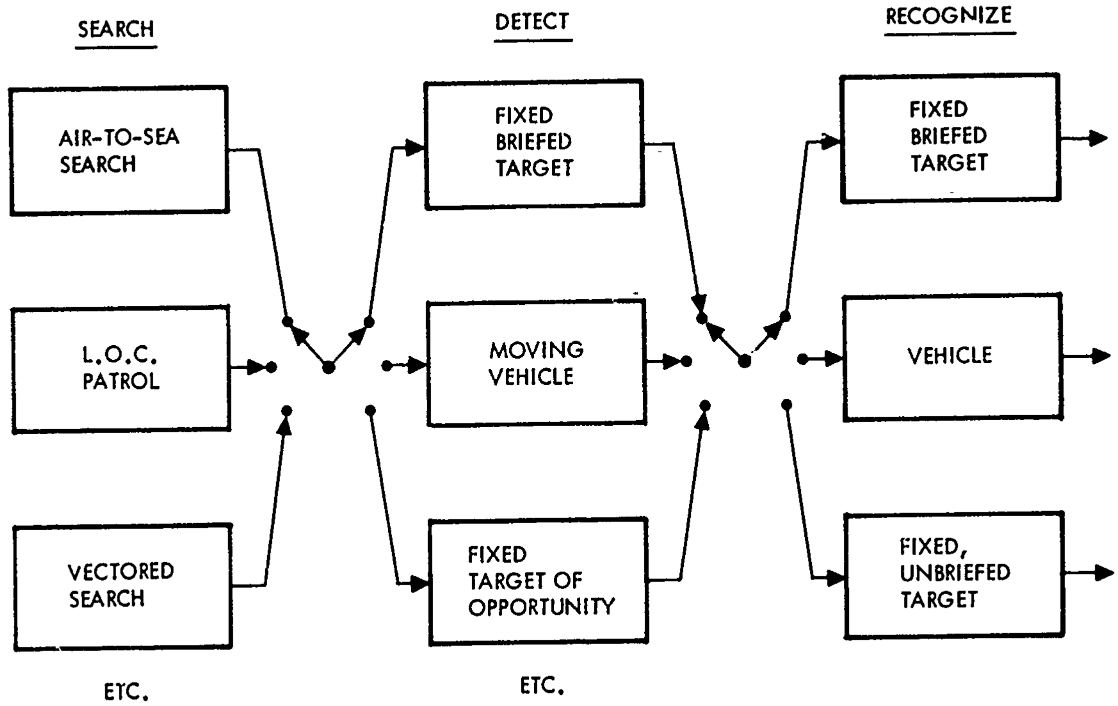

Figure 2. Example of Articulated Target Acquisition Model

air/sea search versus pre-briefed search for a fixed target on land. In the first case, a search pattern is set up; any visual discontinuity is inspected to see whether or not it is the target. In the second case, a series of terrain features is fixated and identified, leading to an expected target area. Target acquisition can take place without actual visual contact with a target object as such.

A second potential problem has to do with the data flow through each node in the network. If a new recognition model is introduced which depends upon, for example, the texture of the target image, then some characteristics of image texture must be input to the "Recognition" block. But the existing earlier blocks may not supply such information. The necessary "fix" may, in essence, involve the construction of an entire new chain of submodel blocks.

A COLLECTION OF MODELS

Articulated, multi-purpose models, as considered above, appear to have certain rather severe shortcomings. The question must be raised as to whether a collection of different models (as now exists) may be a better solution to the problem. The search and acquisition processes in sea search, LOC patrol, and area reconnaissance may be so different as to justify a separate (and hopefully simple) model for each.

The comments in earlier sections, relative to terrain characteristics, briefing materials, etc., are really most germane to search for a specific, fixed target in a known location. A purely optical model, with a visual lobe moving in a systematic pattern, is perhaps adequate for sea search. A "push broom" model with a narrow, systematic search pattern directed toward compact targets (vehicles) would be appropriate to line of communication patrol.

Possibly the most difficult situation to model, starting from the present state of affairs, is the general search of an area for any object or activity of military interest. No existing model approaches the representation of an observer with a general sensitivity of unusual amounts of traffic, glints from machinery, dusty foliage along trails, drying laundry, cut trees, and the whole gamut of indicators reported by experienced aerial observers. This observation brings the question of "Alternative Approaches" back to the original question implied in the contract work statement - namely, how to provide for the more subjective, cognitive elements of some search/acquisition tasks.

A Model Format for Area Search

As mentioned above, the kind of search situation which seems to be least well represented by most existing models is one in which an observer is searching an area for a variety of things, at least some of which will not be expected. Such a search task is characterized by multiple "targets," targets found by indirect indicators, screened or camouflaged targets, and generally myriads of confusing objects.

Observer responses must include, in addition to "detection" and "recognition," some indication of degree of relevance of a particular object to one or more target classes, some way of accommodating mis-recognition, non-detection, and confusion among target classes. Also, the likelihood of these and other response categories should be sensitive to briefing type and recency, familiarity with terrain, etc.

One existing model which has some of the required characteristics is the CRESS/SCREEN series.[16] Among other features, the model permits the specification of as many as 750 objects in 40 groups, and computes probabilities of mis-recognition and mis-identification as well as the more usual quantities.

A fundamental decision which must be made early in the formulation of a model has to do with search. Three basic approaches are possible:

(1) Search is systematic and, hence, predictable in detail (the VISTRAC model makes such an assumption). For each search glimpse, the detectability of any object in the visual field can be computed.

(2) Search is random and, hence, predictable only statistically (several models assume random search). The likelihood of detecting any object is, then, dependent upon chance as well as upon its optical properties.

(3) Search behavior depends upon the objects in the search field, and thus is predictable, given an adequately detailed description of the entire visual field. Here, the likelihood of detecting a target (or non-target) object depends upon its optical properties and the observer's expectations.

The selection of one of the above search philosophies will dictate the form of the term which computes likelihood of fixating any particular object within the field. The value of the likelihood of fixation will depend upon the perceived optical properties of each object, and its resemblance to one or more of the target indicators being sought.

For each object fixated, a complex set of possible decisions can be visualized. A beginning at such a decision matrix occurs in CRESS-SCREEN. For example, the following expression is used to compute probability of mis-recognition:[17]

---

[16] NWC TP 5536. See Footnote 1

[17] NWC TP 5536, p. 38. See Footnote 1.

$$P_{MR} = (4\ P_{MRA})\ P_R\ (1 - P_R)$$

where P_{MRA} is judged average probability of mis-recognition

P_R is computed probability of recognition

A far more complex decision set can be constructed as illustrated in Fig. 3. Here twenty-five possible combinations of "actual status" and "perceived status" of a fixated visual stimulus are represented. The likelihoods associated with each cell will be a function of briefing, of the size and composition of the sets of target and non-target objects in the field. The problem of determining likelihoods for each of 25 cells for each of several hundred visual features is challenging, and may be totally impractical. However, it appears to be the direction in which model development should move if the general, area search situation is to be represented adequately.

To represent an entire search mission, the kind of decision set just described must be evaluated for each fixation; the likelihoods for various outcomes on later fixations will then be contingent upon the outcomes of earlier fixations. Some scheme must be developed to prevent the infinite expansion of the alternative sets of outcomes. The scheme would probably take the form of a statistical treatment applicable to an ensemble of glimpses, dropping out the detailed evaluation of each cell for each possible glimpse location.

<table>
<tr><td colspan="2"></td><td colspan="5">APPROPRIATE RESPONSE</td></tr>
<tr><td colspan="2"></td><td>HIGH CONFIDENCE IN TGT. IDENT. DESIGNATE</td><td>RAISED CONFIDENCE; SEEK CONFIRMATION</td><td>RAISED CONFIDENCE; SEEK CONFIRMATION</td><td>LOWERED CONFID IN DET., REC., OR IDENT.</td><td>CONTINUE SEARCH</td></tr>
<tr><td colspan="2">POSSIBLE DECISIONS →</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td rowspan="5">TRUE SIGNIFICANCE OF FEATURE</td><td>1
A CRITICAL TARGET FEATURE</td><td>CORRECT</td><td colspan="2">CONSERVATIVE INTERPRETATION</td><td rowspan="3">ERRONEOUS REJECTION</td><td>MISSED IDENT</td></tr>
<tr><td>2
A TARGET-CLASS FEATURE</td><td rowspan="2" colspan="2">INFLATED CONFIDENCE</td><td>CORRECT</td><td>MISSED RECOG</td></tr>
<tr><td>3
A SIGNIFICANT FEATURE, TARGET-RELATED</td><td>CORRECT</td><td>MISSED DET</td></tr>
<tr><td>4
A SIGNIFICANT FEATURE, NON-TARGET RELATED</td><td>WRONG I.D. & LOST INFO</td><td>WRONG REC. & LOST INFO</td><td>WRONG DET & LOST INFO</td><td>CORRECT</td><td>LOST INFO</td></tr>
<tr><td>5
AN ARTIFACT OR IRRELEVANT FEATURE</td><td>WRONG IDENT</td><td>WRONG REC</td><td>WRONG DET</td><td>CONSER-VATIVE INTERP</td><td>CORRECT</td></tr>
</table>

Figure 3. Possible Target Decision Matrix (Assume that a "Feature" is Fixated on the Nth Glimpse)

CONCLUSIONS

The gross conclusion which emerges from the considerations reviewed in this report is that the optimal form for a target acquisition model is so dependent upon (1) the objectives of the user, (2) the class of situation being modeled, and, less fundamentally, (3) the intellectual orientation of the model builder, that there is little chance of a reduction to one or two "super-models" to meet all requirements.

Acceptance of the initial conclusion does not, however, imply that the present-day proliferation of models is optimal. In fact, certain classes of potentially useful models appear to have been neglected; other categories are almost certainly over-populated.

Table 2 is an attempt to fit known models to probably important requirements. The divisions are coarse, but serve to illustrate the apparent imbalance of model development to date. Insofar as this crude analysis is correct, it would imply that the following alternative approaches to visual target acquisition need to be pursued:

1. Simpler models for operational use for all classes of missions (generally similar to existing RAND[18] and MINIMAL[19] models).
2. Simple, multiplicative modifiers to existing models, to incorporate cognitive/subjective factors, for parametric study of simple search situations.
3. A new, probably complex, approach to modeling the multi-objective, area search situation, for parametric studies.

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18 The RAND Corp. "Target Detection Through Visual Recognition: A Quantitative Model" by H. H. Bailey. Rand Memorandum RM-6158/1-PR, February 1970.

19 Naval Weapons Center. "A Simplified Air-to-Ground Target Acquisition Model" by C. P. Greening, Autonetics Division, Rockwell International. China Lake, Calif., NWC, August 1974. (NWC TP 5680.)

Table 2. Classes of Models - Existing, Modified and New

Purpose	Type of Mission	Most Relevant Existing Models	Necessary Changes
Operational	Vectored	RAND (Bailey)	Validation
		TAWG "Minimal" (Greening)	Validation & extension
"	LOC or Route Recon.	None	New, simple
"	Area Search (Multi-Objective)	None	New, hopefully simple
Parametric Studies	Vectored	MARSAM II; VISTARAQ; etc.	Add cognitive/subjective multipliers
	LOC or Route Recon	VISTARAQ	Little or none
	Area Search (Multi-objective)	SRI CRESS/SCREEN	Extension & validation of decision matrix; add cognitive/subjective elements or new approach.

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